S[redacted]

RADIATION HAZARDS DURING ATOMIC WARFARE (U)

by

LT COL N. M. LULEJIAN

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~

NOVEMBER 1954

HEADQUARTERS
AIR RESEARCH & DEVELOPMENT COMMAND
BALTIMORE, MD.

S[redacted]

ACKNOWLEDGEMENTS AND A REVIEW OF THE WORK OF OTHER AGENCIES IN THIS FIELD

Most of the information concerning the radioactive contamination levels during CASTLE test Operation were first obtained from Dr. Dunning of the Division of Biology and Medicine of the AEC. He kindly transmitted to us the NYOO airplane readings of the contaminated islands taken by Merrill Eisenbud's unit. Dr. Dunning also transmitted to us the JTF-7 radiological survey data and the gamma ray readings of Rongelap, Rongerik and Alinginae which were made by Dr. Scoville of AFSWP and which helped considerably in the final analysis of CASTLE BRAVO shot. The above information was used to prepare a preliminary report (See Reference 6). Subsequently most of the same data became available in the Project 2.5a report (See Reference 12). Other personnel who kindly furnished us basic data were Lt Col Bommott of JTF-7 and Col Houghton of AFSWC. We have worked closely in the past with RAND in the problem of radioactive fallout up to but not including CASTLE data. At this point the RAND and ARDC analyses vary considerably. Primarily RAND believes that 90% of the activity in the cloud is in the mushroom and only 10% in the stem. ARDC analysis shows 80% activity in the stem and only 20% in the mushroom most of which is non-scavengable or falls out at much later times. RAND assumes fallout originates from 100,000 ft. msl for CASTLE BRAVO, ARDC assumes that the fallout in the first 15 to 30 hours does not come from above 60,000 ft. The USNRDL scaling of Jangle-Surface shot did not consider any fallout beyond 3 to 5 miles downwind of ground zero. Within this area only 10 to 15% of the total residual activity was deposited. The ARDC Analysis (See Reference 1) showed that the immediate downwind fallout reached as far as 90 miles downwind and this fallout area accounted for approximately 85% of the total activity. It is presumed that the NRDL scaling model will be altered to account for this discrepancy. It appears to us that the AFSWP Report 507 adopted the NRDL scaling model for CASTLE BRAVO shot. Undoubtedly AFSWP and NRDL have in more recent work changed their scaling model, but such changes are not yet made known to us. The U. S. Weather Bureau and the Air Weather Service have studied the fallout problem primarily from the point of view of minimizing contamination during atomic test operations. The Army Chemical Corps and the Signal Corps have also studied the fallout problem. It is clearly shown above that at the present time the effort in this field of endeavor throughout the Defense Department, AEC and the Weather Bureau is quite extensive. It is hoped that at some future date a coordinated picture will be obtained on the mechanism and magnitude of the fallout.

RES[redacted]DATA
At[redacted]y Act 1946

[redacted]

S[redacted]

ABSTRACT

1. The first shot of CASTLE Test Operation is analyzed in detail, and this, together with Jangle-Surface shot, is used for scaling of fallout intensities and areas for yields of 1 KT to 225 MT. A method is also given to predict the fallout for any scaled height. Table I (see following page) gives the 48 hour integrated dose in roentgens within downwind contaminated areas in square miles for different yield bombs exploded on the surface. The values given in Table I are generally much higher than the predictions made by other agencies in this field. It is possible to determine the extent of downwind contamination for any yield bomb detonated at any scaled height by the use of Table II (see following page).

2. The offensive and defensive implication of such highly contaminated areas are discussed. Calculations are made on the dosage received by aircrews accidentally penetrating young atomic clouds from multi-megaton bombs. Estimates are given on the contact beta hazard to the hands of maintenance personnel from contaminated engine parts.

3. The fallout picture is given for all of the United States when 111 bombs of 15 megaton yield are surface detonated over 106 cities whose population is 100,000 or more and on five other selected airbases. This is illustrated graphically in Figure 11. An inspection of this Figure shows that there is "no place to hide" in this country under above listed circumstances.

RE[redacted]ATA

Atomi[redacted]1946 DOE ARCHIVES

C4-236767

[redacted]

TABLE I [redacted]

48-hour Integrated Dose in Roentgens	Areas in Square Miles for the Following Yield (KT) Surface Burst Bombs *										
	1.75	10	100	500	1,000	5,000	15,000	45,000	60,000	100,000	225,000
13,000	0.013	0.22	3.18	25	44	288	1,000	3,620	5,030	8,900	22,600
3,330	0.042	0.47	6.9	53	95	620	2,160	7,820	11,000	19,200	48,800
670	0.42	4	47	258	560	3,060	10,000	33,000	43,600	76,000	183,000
250	0.84	7.5	81.4	430	900	4,750	15,000	47,200	62,200	106,000	246,000
33	1.75	14.5	147	750	1,560	8,100	25,000	76,500	100,000	173,000	400,000

[redacted]

BEST AVAILABLE COPY

TABLE II

λ	Percentage Fallout	Burst Height Above Terrain for 15 MT Bomb
1.0	0%	5,000 feet
0.45	30%	2,000 feet
0.2	50%	1,000 feet
0.0	80%	0
- 0.1	95%	- 450 feet (underground)

* For a justification of Table II, see the Appendix and References 1 and 6.

$$\lambda = \frac{h}{500\,(w/20)^{1/3}}$$

where

h = height above terrain in feet

w = bomb yield in kilotons [redacted]

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~

C4-23676

7

8

IV. Dosage to Aircrews Penetrating Young Atomic Clouds

a. During UPSHOT-KNOTHOLE Atomic Test Operation, a project was established to measure the dosage within the young atomic cloud by means of cannisters and droned aircraft (2). The results showed that dosage accumulated was less than 50 roentgens for the flight of an aircraft through a four minute old cloud from a bomb of 26 KT when the speed of the aircraft was 400 knots. Dose rates within the cloud ranged from 38,000 r/hr to 7500 r/hr when times of entry varied from 2.7 to 5.2 minutes. The average dose rate in a cloud was represented by:

$$D = 1.31 \times 10^{5}\, t^{-2.06} \quad \text{- - - - - - - - - - - - - - Equation 1}$$

In this equation time, t, is given in minutes after bomb detonation, and average dosage, D, in roentgens per hour. Reference 2 indicates that this Equation applies for the time period of 2.5 to 25 minutes after bomb detonation. To prepare this equation, Reference 2 used not only the UPSHOT-KNOTHOLE, but also the GREENHOUSE data available at the time. Recently, Plank and Steele (3) have shown that for CASTLE data, the following relation applies:

$$D = k\, t^{-4} \quad \text{- - - - - - - - - - - - - - - - - - Equation 2}$$

Equation 2 is said to be valid for times from two hours to six hours after bomb detonation. Using Equation 2, Captain Steele of SWC has shown that in order to get 170 roentgens accumulated dosage, the cloud should not be penetrated earlier than thirty minutes after bomb burst, if the cloud diameter or the stem diameter is ten miles in length. Similarly, the times are 35 and 45 minutes for fifteen and fifty mile cloud diameters. In this analysis it was assumed that the activity within the cloud was uniform throughout. It will be shown in subsequent sections that for a surface burst megaton yield weapon, the stem may have 10 to 20 times the activity per unit volume when compared to the specific activity of the mushroom.

b. It is our opinion that there is a good physical explanation why there is a break in the curve of dosage rate with time within the cloud, as shown in Equations 1 and 2 above. The explanation of this phenomena is to be found in the fact that for surface or tower shots considerable amount of sand and soil debris is sucked up into the cloud and it is eventually coated with fission products which later fall out due to their own gravity. Colonel Pinson (2), during Operation UPSHOT-KNOTHOLE, measured the dose rate within the cloud which was burst high enough to be considered a pure air burst. Under these circumstances, there were no active soil particles to be found

RES[redacted]ATA
At[redacted] 1946

[redacted]

TABLE III

Dosage Accumulated in Passing through a 15MT Cloud at Different Altitudes for Different Times of Cloud Penetration by an Aircraft whose True Air Speed is 400 Knots. [redacted]

LETED

Flight Altitude Above msl Thousands of Feet	Time of Cloud Penetration in Minutes after Bomb Detonation	Length of Flight Path Through Cloud in Thousands of Feet	Specific Activity	Time Spent in Cloud (Minutes)	Gamma Dosage Accumulated in Cloud in Roentgens	Maximum Time Spent in Disorganized Cloud	Maximum Gamma Dosage that may be Accumulated While in Cloud
h	t_a	y	$\frac{s_2}{s_1}$	t_b	D min	t_b max	D max
20	30	68.7	17.3	1.72	75	5	220
20	45	68.7	17.3	1.72	30	10	150
20	60	68.7	17.3	1.72	10	15	60
30	30	68.7	17.3	1.72	105	5	300
30	45	68.7	17.3	1.72	40	10	200
30	60	68.7	17.3	1.72	15	15	80
40	30	68.7	17.3	1.72	160	5	450
40	45	68.7	17.3	1.72	60	10	300
40	60	68.7	17.3	1.72	25	15	120
50	30	68.7	10.	1.72	145	5	400
50	45	68.7	10.	1.72	55	10	270
50	60	68.7	10.	1.72	20	15	110
60	30	120.	0.10	3.	5	9	15
60	45	120.	0.10	3.	2	18	8
60	60	120.	0.10	3.	2	27	4
70	30	150.	0.05	3.75	9	10	25
70	45	150.	0.05	3.75	3.5	20	17
70	60	150.	0.05	3.75	1.5	30	7

21

[redacted]

RESTRI[redacted]DATA

[redacted]

APPENDIX

CONSTRUCTION OF FALLOUT PLOTS

A. Method of Plotting Fallout

The fallout plot or radex plot in its simplest form consists of plotting winds from the surface up to the height reached by the atomic cloud. The method of plotting is merely the vector addition of winds. The winds are weighted to account for the amount of time they spend through each layer of the atmosphere. It is assumed that the soil particles have a density of 2.5 gm/cm^3 and that rate of fall follows Stokes' Law:

$$v = \frac{2 g r^2 (\rho_2 - \rho_1)}{\eta} \qquad \text{---Equation 11}$$

where

$V =$ rate of fall

$r =$ radius of spherical particles

$\eta =$ coefficient of viscosity of air

$g =$ acceleration of gravity

$\rho_2 =$ density of particles

$\rho_1 =$ density of air

Although viscosity of air varies with temperature, for sake of simplicity, viscosity is usually assumed to be constant. Actually, an accurate use of viscosity in the Stokes' Equation is not justified, because the fallout particles are not all spherical, nor are they all of equal density. Errors introduced by these assumptions far outweigh a more rigid analysis of the change of viscosity of air with temperature. Also, the variation of winds aloft with time and space make it difficult if not impossible to determine with great enough accuracy the fallout area to justify the use of a more accurate rate of fall formula. Reference 16 uses different rates of fall formulas for different size particles. Although this may be justified for particles significantly larger than 100 microns and also for particles less than 10 microns, an inspection of Table XVIA shows that more than 50% of the total activity of a surface burst bomb is scavenged out by

[redacted]TA
At[redacted]t 1946

[redacted]

particles whose diameters are from 20 to 100 microns. In view of this, we neglect corrections to the simple Stokes' Law. The Air Weather Service Manual on Fallout and Radex plots (19) and Colonel George Taylor's method of Radex Plotting during Operation GREENHOUSE (20) describe the method quite adequately. For the following winds aloft information the simple radex plot is given in Figure 1A.

Altitude in Thousands of feet Above Mean Sea Level	Wind Direction	Wind Speed In Knots
0	90	5
5	120	8
10	150	10
15	160	15
20	180	20
25	230	25
30	270	30
35	270	40
40	290	45
45	330	50
50	70	25
55	80	20

A spherical particle of 70 micron diameter and a density of 3 gm/cm^3 will fall approximately at the rate of 6,000 ft/hr or at a rate of 1 knot. Hence, the trajectory plotted in Figure 1A shows the locus at sea level of 70 micron particles falling from different heights. In Figure 1A, the heights from which the particles have arrived is listed in thousands of feet. For example, the arrow line between points B and C of the figure represent fallout of 70 micron particles arriving from an altitude of 37,500 to 42,500 ft. above sea level. Since Stokes' Law indicates that the fall velocity of particles is proportional to the square of the particle radius, it is at once evident that 100 micron particles would fall at approximately double the speed of 70 micron particles and similarly 140 micron particles would fall four times as fast as 70 micron particles while 50 micron particles fall at approximately one half the speed of 70 micron particles. This means that from a given height, the smaller particles would fall further away from ground zero than the larger particles. For example, in Figure 1A, it is assumed that ground zero is at 0 and a 70 micron particle originating at 42,500 ft. will arrive at point C, hence 100 micron particles would fall at point D and 140 micron particles at E. By utilizing this method, it is possible to determine quite simply the complete fallout plot of any sized particle as indicated in Figure 1B. By the use of Stokes Law (Equation 11) it would be simple to find the times of fallout. For example, the fallout time at points C, D and E would be approximately 7, 3.5 and 1.75 hours respectively. For greater details consult

[redacted]

RE[redacted]A
Atomi[redacted]t 1946

BEST AVAILABLE COPY

DOE ARCHIV

C4-23676

40

[redacted]

subsequent sections of the appendix or references 19 and 20.

B. Detailed Study of Fallout from First Shot of CASTLE Test Operation

1. Existing Wind Distribution

In order to construct correct fallout plots, adequate winds aloft information is required before, during and after shot time. Unfortunately, during the first shot of CASTLE Test Operation (this was called BRAVO shot) there were no winds available from the shot island. The Navy (SS Curtiss) made some winds aloft measurements at a point south of ground zero. However, at Eniwetok, Kwajalein and Rongerik (See Figure 1, Reference Map, for locations of these islands) routine winds aloft information were taken.

2. Variation of Winds Aloft with Time and Space and its Effects on Radex Plotting

A study of such wind data indicates that although there was a time variation of the winds aloft soon after zero time, there was no significant space variation of the winds at a given latitude. This means that the Eniwetok, Curtiss and Rongerik winds all varied to approximately the same degree with time. In view of this, it was thought worthwhile to use average values of Eniwetok, Rongerik and Curtiss winds for H-hour and Eniwetok and Rongerik wind averages for times after H-hour. Because the correct winds aloft is the key to the proper analysis of CASTLE - BRAVO shot, this wind data is given in Tables VIII, IX, X and XI where the average H-hour, H + 2:15 hours; H + 8:15 and H + 14:15 hour winds are listed.

[redacted]

[redacted]

41

TABLE VIII

H-Hour Winds, Using the Average Values of Eniwetok, Rongerik and Curtiss Winds

Altitude in Thousands of Feet	Wind Direction In Degrees	Wind Speed In Knots
Surface	65	15
1	75	18
2	80	17.5
3	85	16
4	90	16
5	90	12
6	90	4
7	280	5
8	300	5
9	320	8
10	310	10
12	290	9
14	290	12
16	290	14
18	290	18
20	280	20
25	250	25
30	250	33
35	240	40
40	240	40
45	250	40
50	250	30
55	260	12
60	330	15
65	320	3
70	80	27
75	80	13
80	30	30
85	70	47
90	70	37
95	--	--
100	--	--

BEST AVAILABLE COPY

REST[redacted]TA
At[redacted]946

42

[redacted]

TABLE IX

H + 2:15 Hour Winds using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	70	17
1	80	18
2	70	18
3	80	17
4	80	15
5	80	13
6	60	5
7	300	5
8	270	7
9	320	9
10	310	10
12	270	11
14	290	8
16	300	15
18	300	13
20	300	17
25	300	25
30	255	33
35	240	42
40	255	38
45	250	37
50	260	30
55	300	13
60	Calm	Calm
65	Calm	Calm
70	80	13
75	80	18
80	80	36
85	80	13
90	—	—
95	—	—
100	—	—

[redacted]

[redacted]

[redacted]

TABLE X

H + 8:15 Hour Winds using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	70	15
1	80	15
2	90	14
3	90	14
4	100	12
5	100	7
6	180	5
7	180	6
8	320	5
9	280	7
10	290	13
12	300	13
14	290	10
16	310	10
18	290	15
20	290	20
25	260	25
30	260	30
35	260	39
40	250	40
45	260	40
50	270	15
55	260	7
60	Calm	Calm
65	Calm	Calm
70	—	—
75	—	—
80	—	—
85	—	—
90	—	—
95	—	—
100	—	—

BEST AVAILABLE COPY

[redacted]

[redacted]

C4-23676

[redacted]

TABLE XI

H + 14:15 Hour Winds Using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	80	13
1	90	13
2	100	15
3	100	12
4	100	10
5	90	10
6	100	6
7	Calm	Calm
8	50	5
9	280	8
10	280	10
12	300	10
14	330	8
16	320	10
18	320	12
20	300	23
25	270	25
30	260	30
35	250	30
40	240	40
25	260	35
50	280	27
55	280	7
60	90	6
65	270	3
70	Calm	Calm
75	90	20
80	90	32
85	90	42
90	90	46
95	90	46
100	90	54

[redacted]

[redacted]

DOE ARCHIVES

C4-23676

45

[redacted]

This wind information is also plotted in Figure 2 using simple radex plots or simple fallout plots of the winds for 50 micron diameter particles. An inspection of Figure 2 shows that the H-hour average wind plot goes approximately 20 miles NW and N of Rongelap and approximately 40 miles North of Rongerik. The H + 2:15 hour wind, however, shifts 35 to 40 miles south in the area of Ailinginae - Rongelap - Rongerik. The first temptation is to assume that if we use the H + 2:15 hour average winds in place of the H-Hour winds, we get a correct fallout picture, but this is not true since such a fallout plot does not properly account for the actual contamination that is shown in Figures 5 and 6. A detailed examination of Figures 2, 5, and 6 shows that the H + 2:15 hour fallout plot does not correctly take into account the distribution of contamination on Bikini, since according to Figure 2, the islands in the south sector of Bikini Atoll should all have about equal contamination, but Figure 6 shows that this is not true. Similarly, the contamination patterns at Ailinginae, Rongelap, Rongerik and Bikar cannot be justified by the wind pattern of H + 2:15 hours. Figures 5 and 6 were taken from Reference 12. It should be noted that the H + 8:15 and H + 14:15 hour average wind plots (See Figure 2) return to the north of the islands, and appear to parallel the H-hour wind plot more closely than the H + 2:15 hour plots. Figure 2 shows that the winds aloft simple radex plot ascillates considerably in eight hours. In view of such a rapidly changing meteorological situation it is not possible to prepare an adequate fallout plot utilizing one set of average winds for ground zero and assuming that this applies throughout the downwind area during the active fallout period. As indicated in Figure 2, there is a significant change in the winds aloft picture within two hours after shot time. Because of this it is mandatory to utilize a "Time Composite Radex Plot", which takes into account the change in wind direction and speed in the downwind direction. The composite analysis starts at the desired altitude and works the trajectory of a given particle to the ground. This merely identifies the given particle size reaching the surface from a given altitude. When such points are repeated for many particle sizes and from all elevations of the atomic cloud, we obtain the composite Radex Plots shown in Figure 3. Needless to say, such a procedure is time consuming and demands accurate and complete winds aloft information throughout the fallout area. Such information is not available before the fact for operational planning. Certainly, we can't expect forecast winds to be so accurate (± 5° and ± 2 Knots) within all altitudes. Hence, it is our opinion that although it may be worthwhile to use Composite Radex Plots for post analysis of a contaminating event, there is no operational need to perform such detailed analysis before the fact. What is required operationally is an indication of the correct quadrant of fallout, and a guess as to which half of the quadrant may receive the highest contamination. Figure 3 shows the composite fallout plot for 50, 70, 100 and 140 micron particles. It should be noted that this composite plot more nearly agrees with the actual

[redacted]

RE[redacted]TA
At[redacted]ergy Act 194

46

[redacted]

contamination pattern shown in Figures 5 and 6. For sake of simplicity, the 50 micron composite fallout of Figure 3 is plotted separately in Figure 4. A comparison of Figure 4 with Figure 6 shows considerable agreement between the plotted and actual contamination as far as it is possible to do so with a one particle size analysis. In subsequent paragraphs, after we have taken into account the change of particle size with height within the atomic cloud, it will be shown that the Composite Radex Plot also accounts for the contamination pattern in the islands of Bikini Atoll.

3. Assumed Activity and Particle Size Distribution Within the Atomic Cloud at Time of Stabilization

A study of the downwind fallout from the tower shots at the Nevada Proving Grounds (T/S and U/K Test Operations) shows that as the weapon yield is increased from 12KT to 50KT, the mass median particle diameter of the active soil particles within the cloud aerosol appears to decrease from 90 microns to approximately 70 microns. This means that as the yield is increased (or the scaled height is decreased) the gross particle size of the cloud aerosol appears to decrease. However, it should be noted that the experimental evidence in this regard is very meager, hence we can't say with any degree of certainty that as the yield increases the atomic particle size decreases. An inspection of the actual contamination patterns when compared with winds aloft radex plots shows that the soil particles in the lower half of the atomic cloud stem appear to be significantly larger than the particles in the upper half of the stem, and the particles within the mushroom of the cloud are much smaller than the stem particles. In this analysis, we are referring to soil particles mixed into the fireball and sucked up into the cloud. These particles are assumed to be coated with fission products more or less uniformly. An analysis of Jangle-Surface fallout (See supplement to Reference 1) shows that the average particle size distribution within the bottom half of the cloud stem was approximately 140 microns. Because of the inverse "filtering" action of the air, it is assumed that the particle size within the cloud decreases with height. It is anticipated that if a certain amount of soil is tossed into the air, there would be a greater number of small particles at higher elevations as compared to the particle size in lower levels. In this study, it will be assumed that the particle size distribution within a 15 MT atomic cloud at time of stabilization is as indicated in Table XII.

[redacted]

[redacted]

[redacted]

TABLE XII

Altitude Above Mean Sea Level in Thousands of Feet	Average particle Diameter in Microns	Number Distribution of Particle Sizes in Microns in Each Layer of a 15MT Atomic Cloud at Time of Stabilization (4 minutes)			
		10%	40%	40%	10%
h	(d mean)	d_{min}	d_1	d_2	d_{max}
0	140	110	130	150	170
5	130	100	120	140	160
10	120	90	110	130	150
15	110	80	100	120	140
20	100	70	90	110	130
25	90	60	80	100	120
30	80	50	70	90	110
35	70	40	60	80	100
40	60	40	50	70	90
45	50	35	45	65	85
50	50	30	40	60	80
55	50	30	40	60	80
60	45	25	35	55	75
65	45	25	35	55	75
70	40	20	30	50	70
75	30	15	20	40	60
80	20	10	15	35	50
85	10	5	7.5	25	35
90	10	5	5	20	30
95	10	5	5	10	15
100	10	5	5	10	15
110	10	5	5	10	15
120	10	5	5	10	15

The percentage activity in each layer of a 15 MT atomic cloud at time of stabilization (4 minutes after bomb detonation) may be expressed by the following relation:

$PA = k\ d^{x}\ t^{-1.2}$ - - - - - - - - - - - - - - - -Equation 12

Where
PA = Residual radioactivity on a particle (Percentage)

d = diameter of particle

RE [redacted] DATA
Atomi [redacted] 1946

[redacted]

DOE ARCHIVES 75

[redacted]

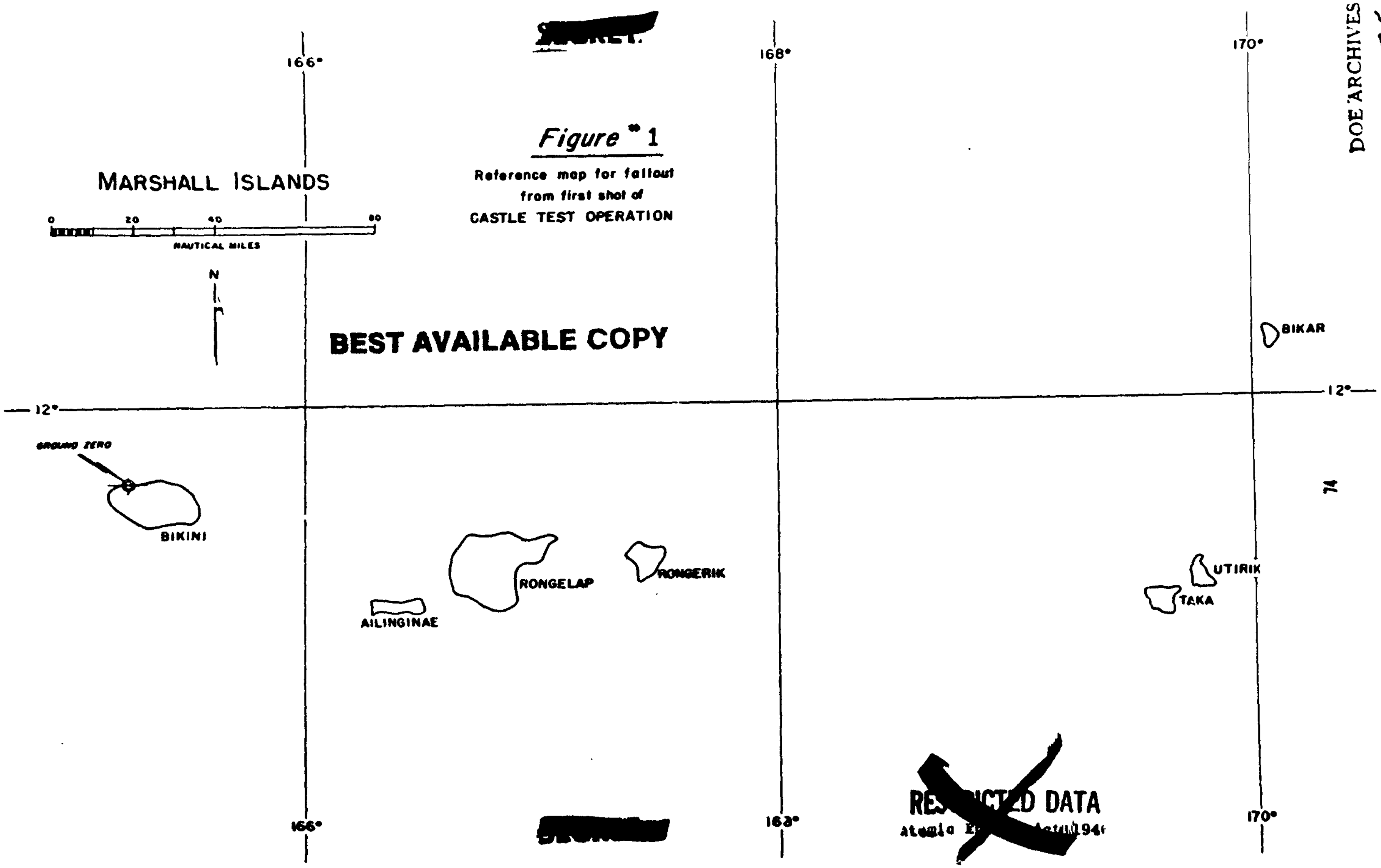


Figure # 1

Reference map for fallout from first shot of CASTLE TEST OPERATION

BEST AVAILABLE COPY

~~RES[illegible]D DATA Atomic E[illegible] Act 1946~~

[redacted]

74

BEST AVAILABLE COPY

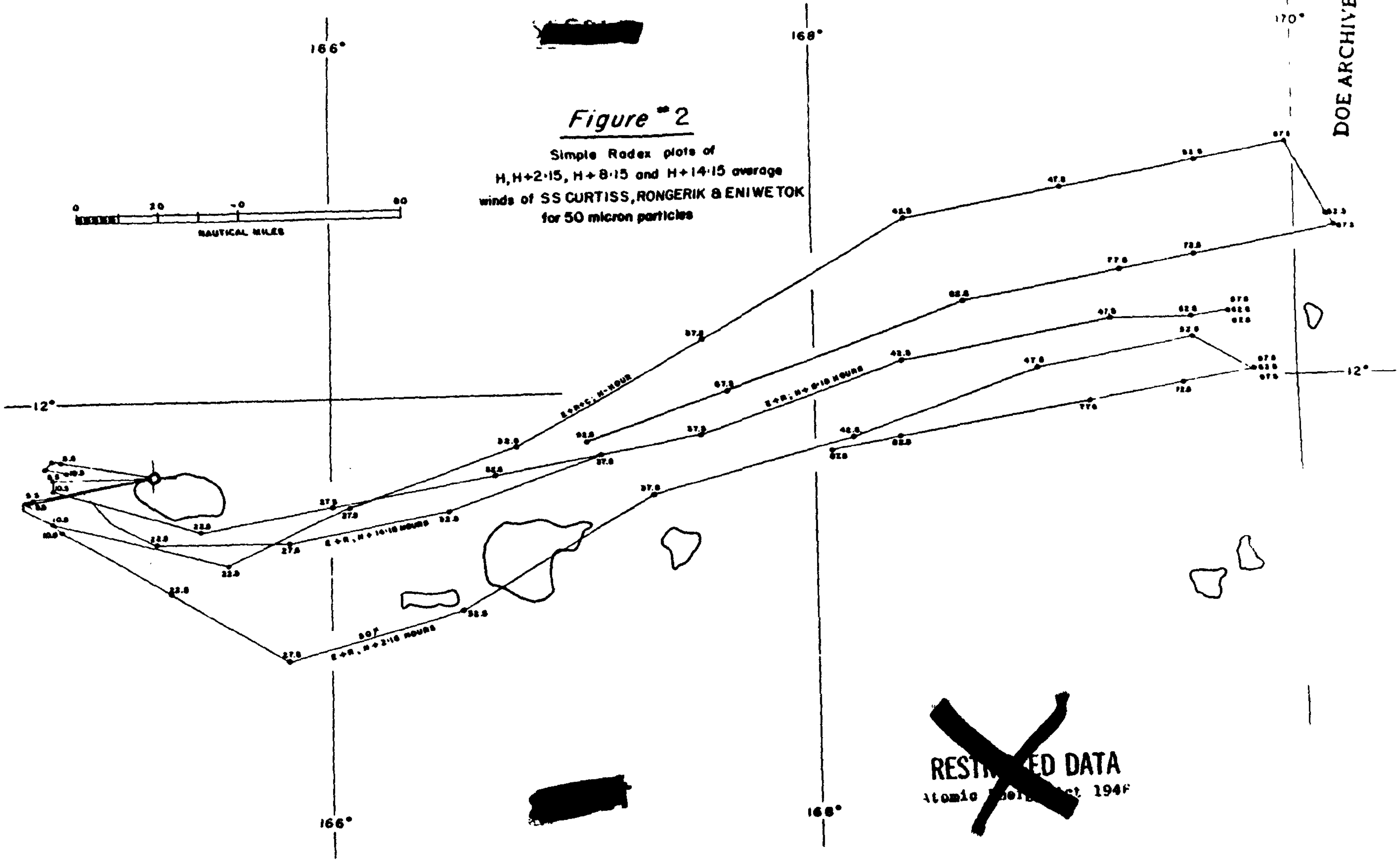
76

DOE ARCHIVES

[redacted]

Figure # 2

Simple Radex plots of H, H+2·15, H+8·15 and H+14·15 average winds of SS CURTISS, RONGERIK & ENIWETOK for 50 micron particles



[redacted]

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~

BEST AVAILABLE COPY

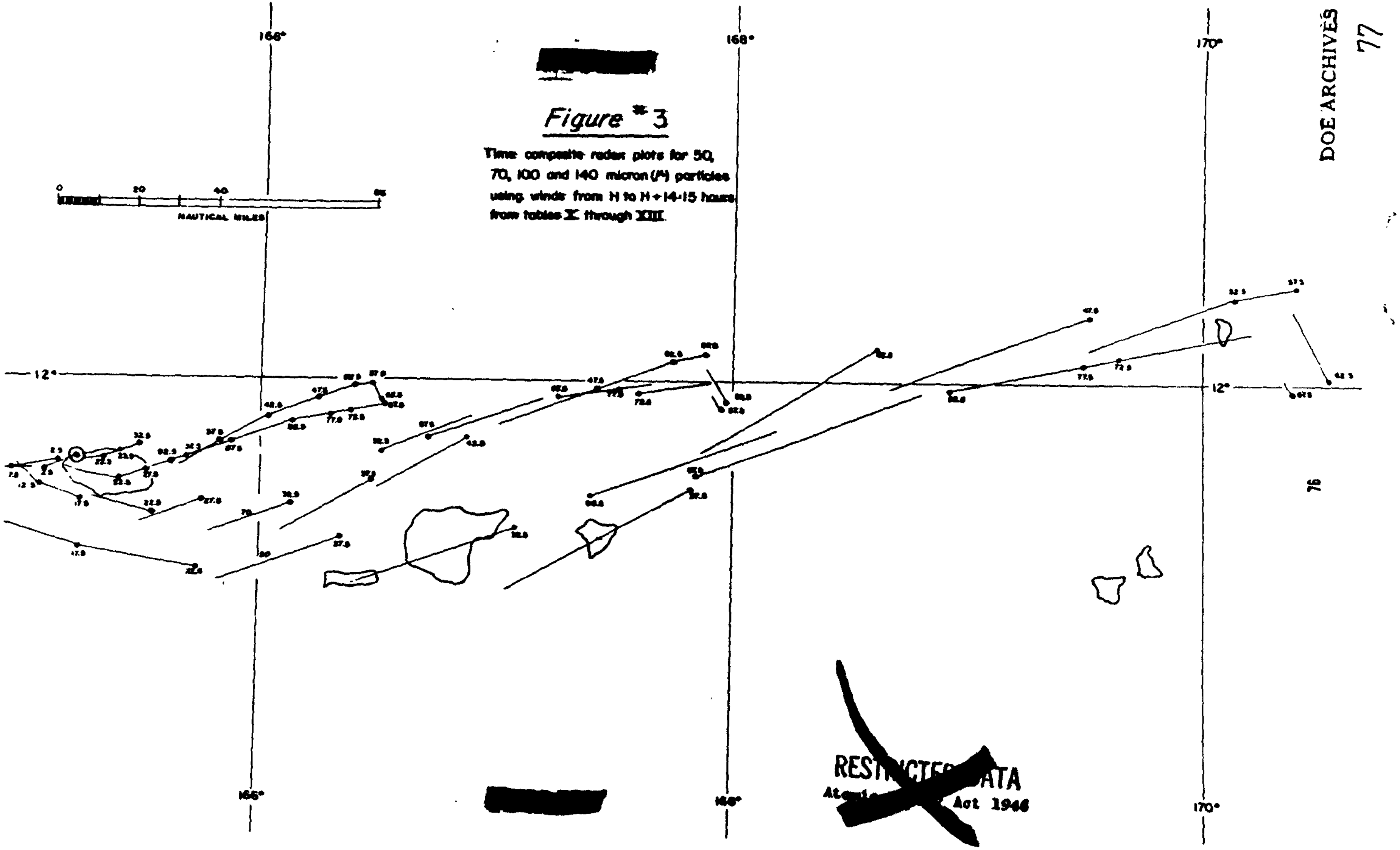
DOE ARCHIVES

77

[redacted]

Figure # 3

Time composite radex plots for 50, 70, 100 and 140 micron (μ) particles using winds from H to H+14-15 hours from tables X through XIII.



[redacted]

~~RESTRICTE[illegible]ATA~~
~~Atom[illegible] Act 1946~~

[redacted]

78

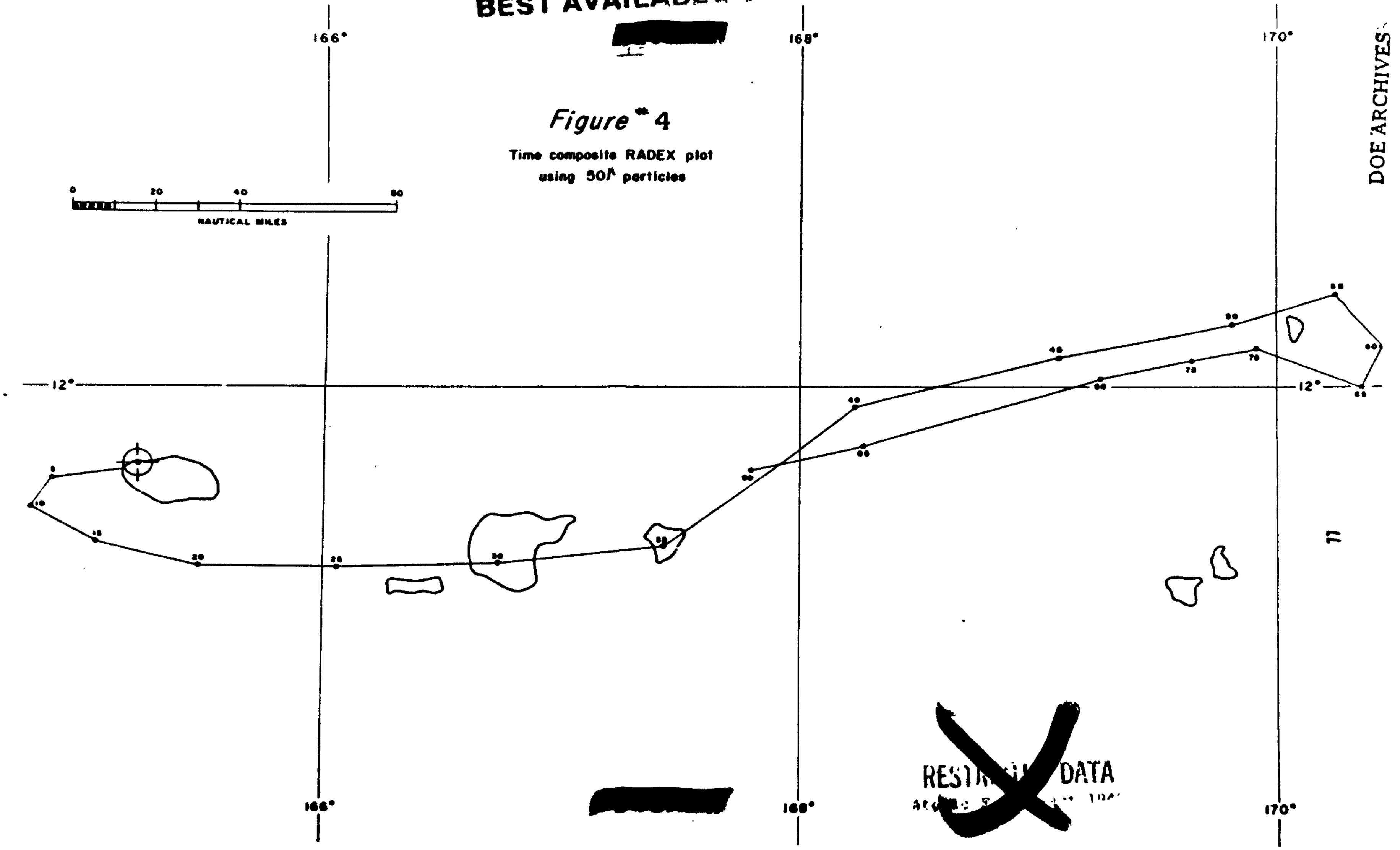


Figure * 4

Time composite RADEX plot using 50μ particles

[redacted]

BEST AVAILABLE COPY

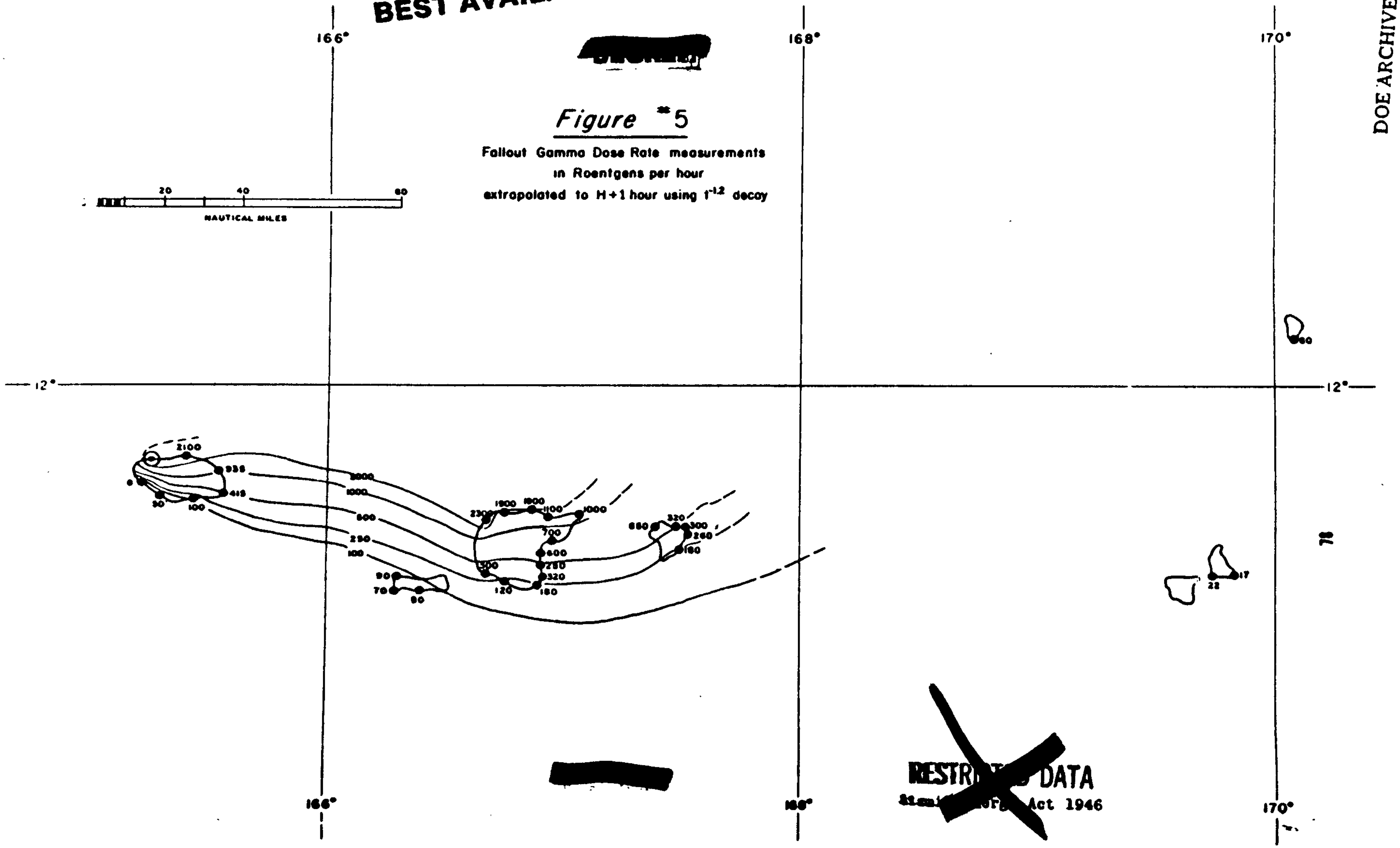
[redacted]

DOE ARCHIVES

79

Figure #5

Fallout Gamma Dose Rate measurements in Roentgens per hour extrapolated to H+1 hour using $t^{-1.2}$ decay



[redacted]

~~RESTRICTED DATA~~

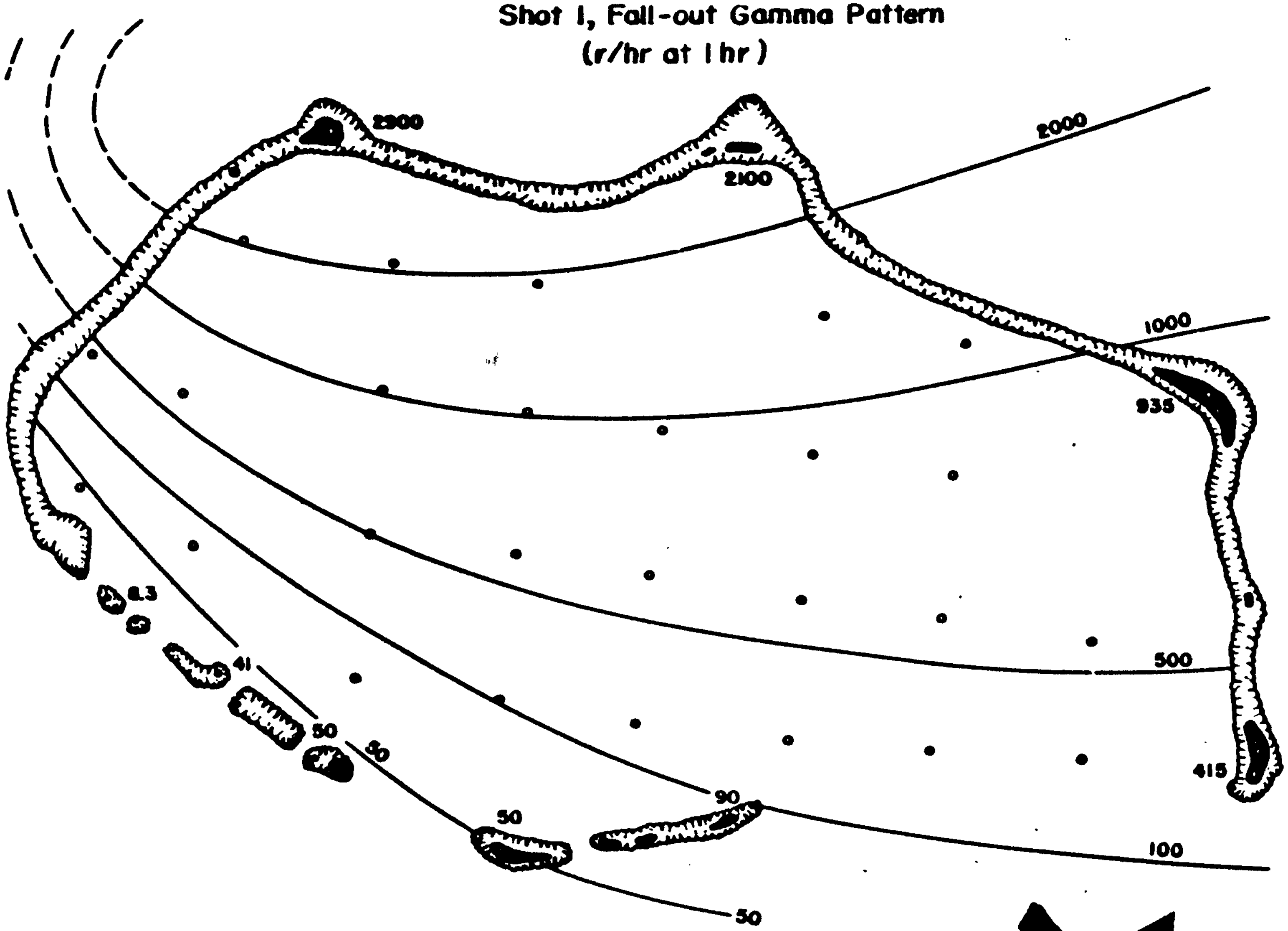
~~Atomic Energy Act 1946~~

Figure

[redacted]

Shot I, Fall-out Gamma Pattern
(r/hr at I hr)

80



[redacted]

~~RESTR[illegible]D DATA~~
~~Atomic [illegible]ergy~~

BEST AVAILABLE COPY

DOE ARCHIVES

81

S[redacted]

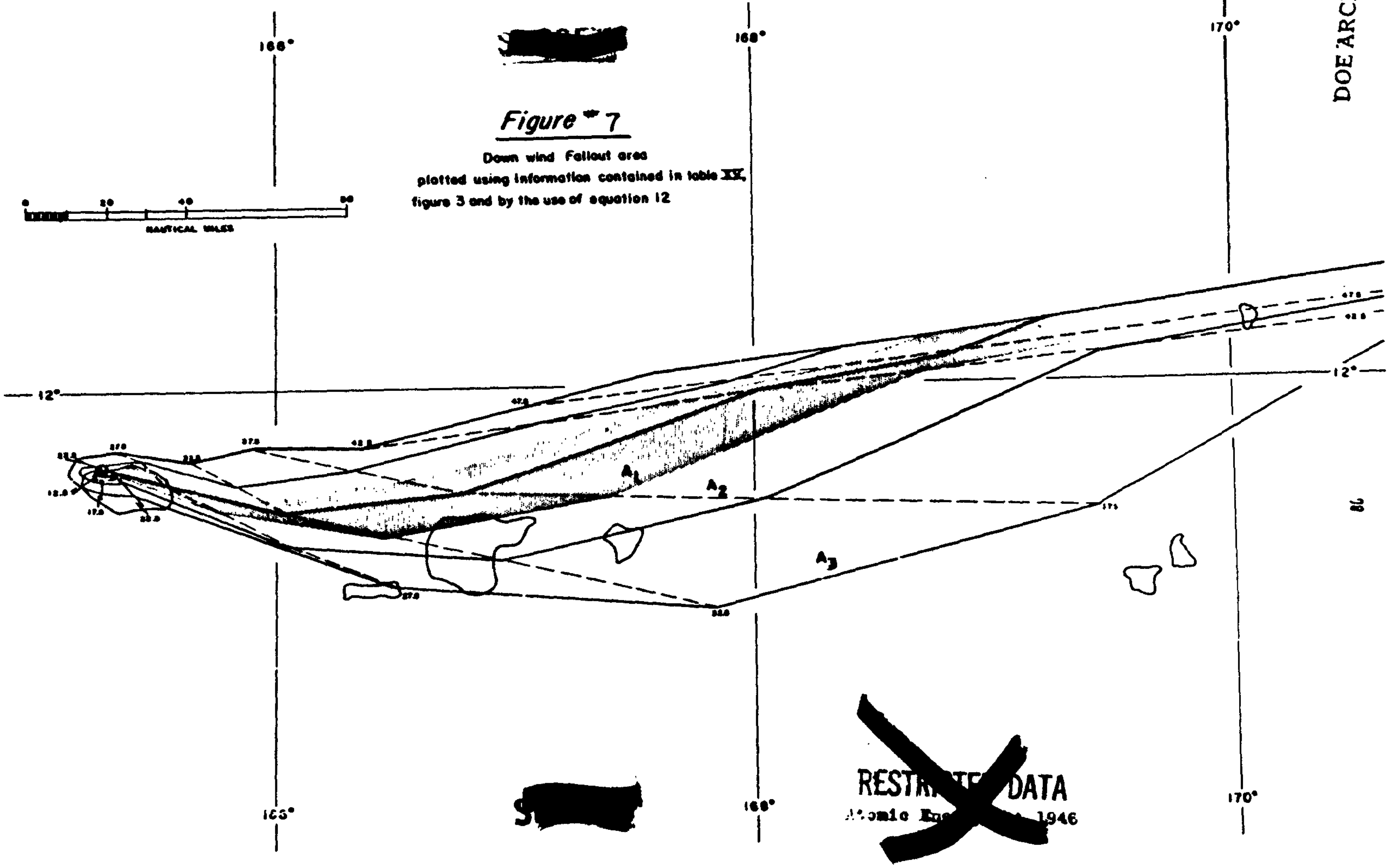


Figure # 7

Down wind Fallout area
plotted using information contained in table XX,
figure 3 and by the use of equation 12

S[redacted]

~~RESTR[illegible] DATA~~
~~Atomic En[illegible] 1946~~

BEST AVAILABLE COPY

[redacted]

DOE ARCHIVES

82

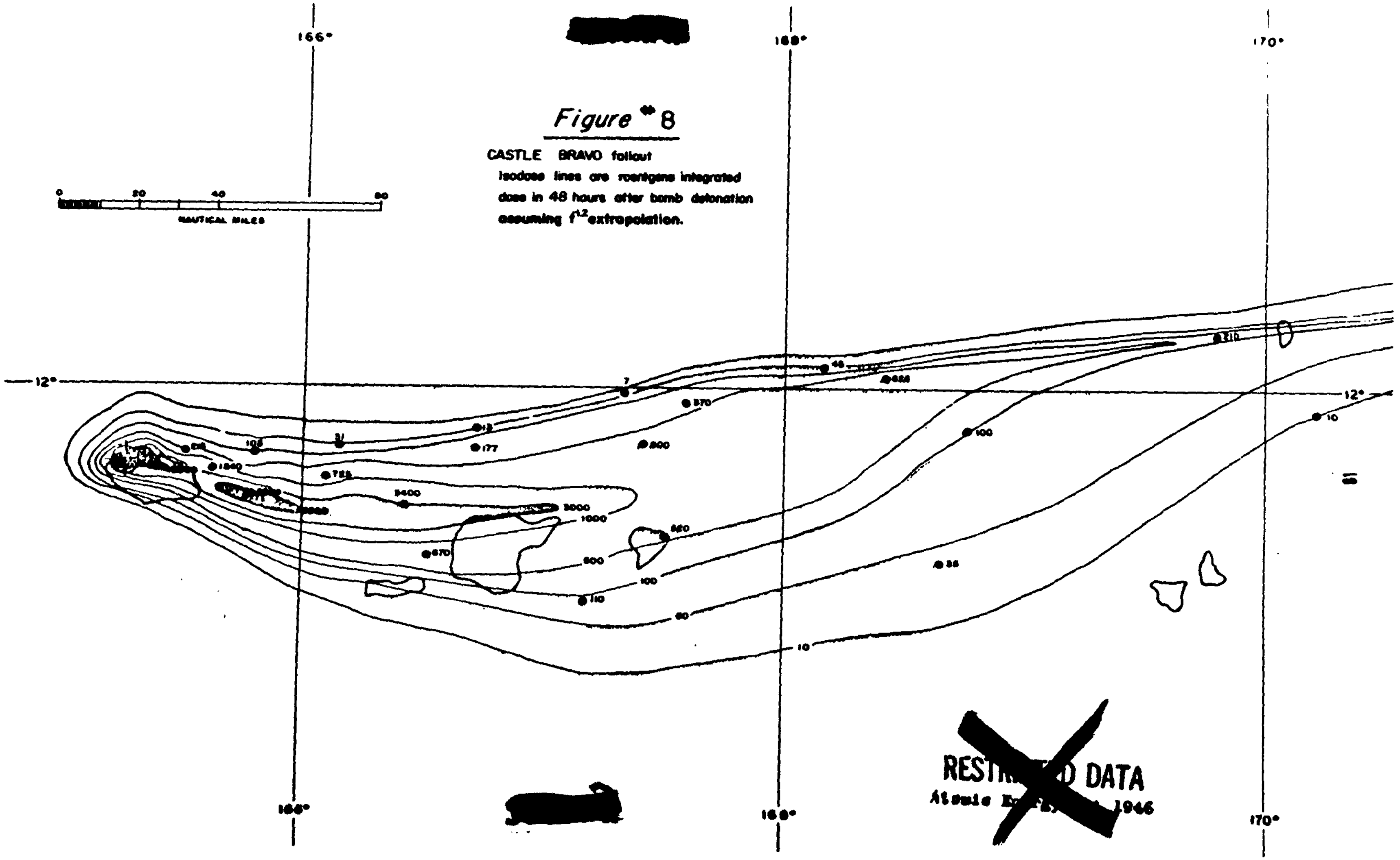


Figure # 8

CASTLE BRAVO fallout

Isodose lines are roentgens integrated dose in 48 hours after bomb detonation assuming $t^{1.2}$ extrapolation.

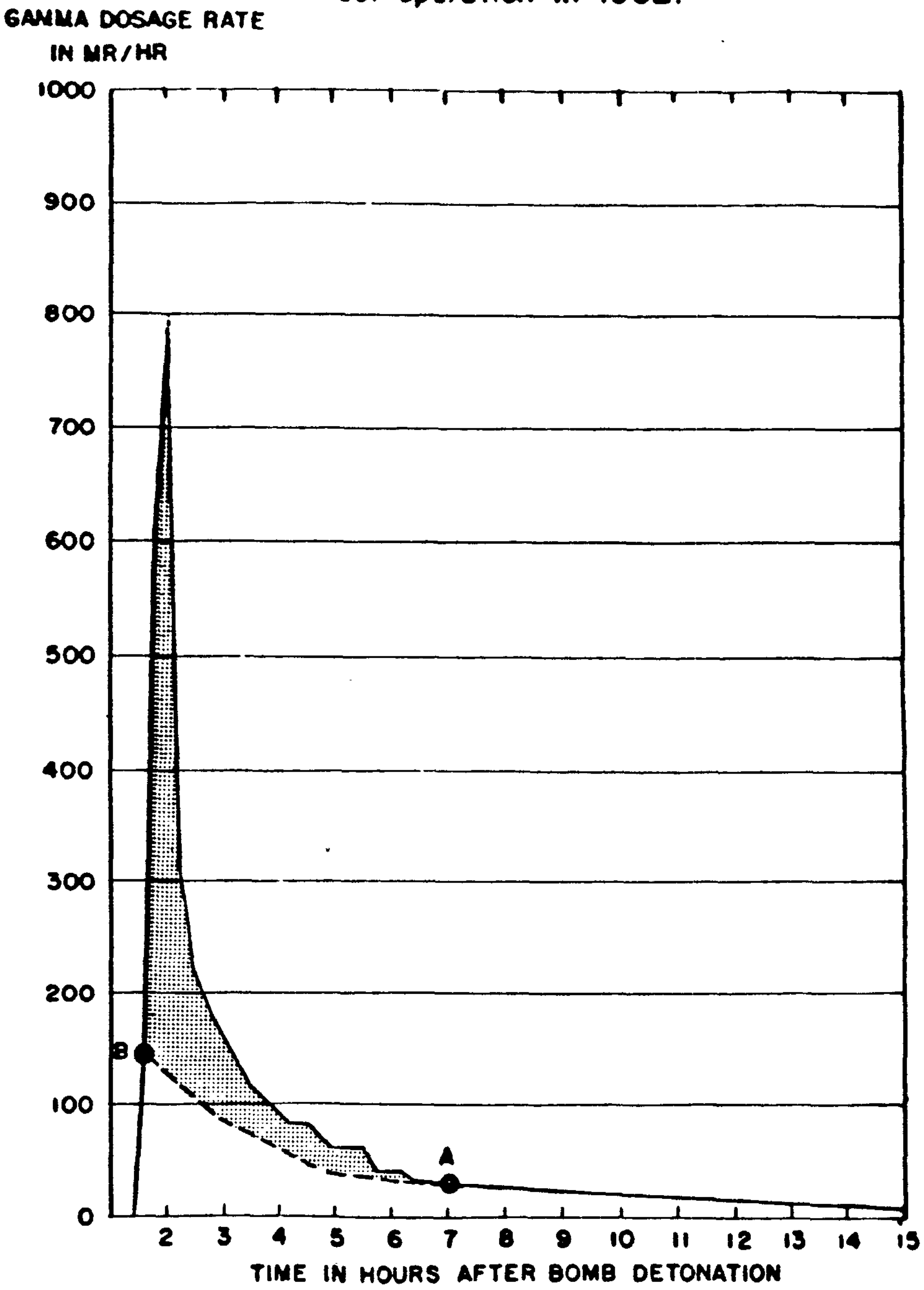
~~RESTR[illegible]D DATA~~
~~Atomic E[illegible] 1946~~

[redacted]

[redacted]

Figure 10

Fallout at lincoln mine, Nevada from shot 5 of tumbler/snapper test operation in 1952.



Shaded portion shows fallout in excess of the $t^{-1.2}$ RELATION

REST[illegible]DATA
Atomi[illegible]ergy [illegible] 1946

DOE ARCHIVES

86

[redacted]

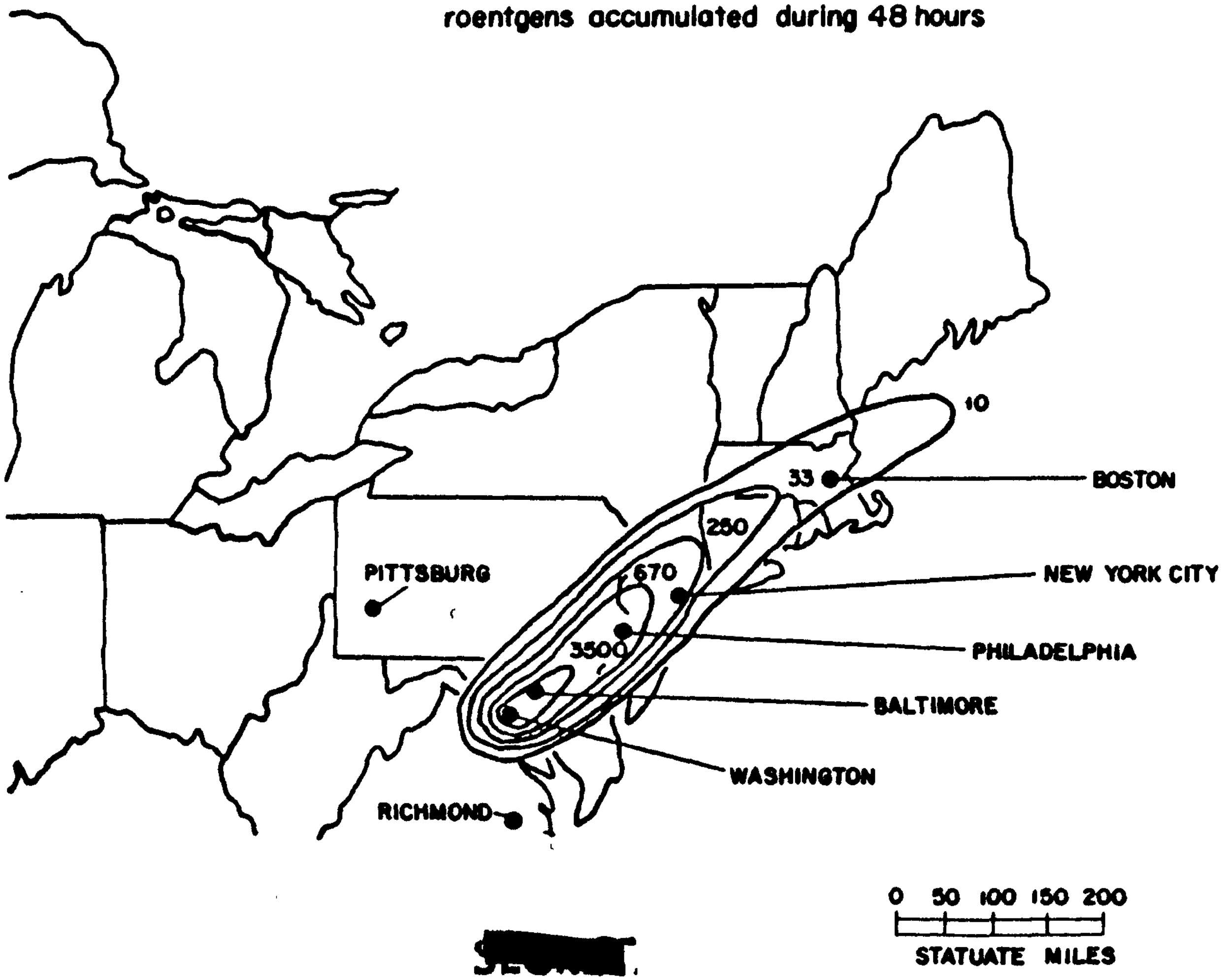
[redacted]

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~

DOE ARCHIVES

Figure #12

Fallout from first shot of CASTLE TEST OPERATION superimposed upon North-Eastern United States. Isodose lines are in roentgens accumulated during 48 hours

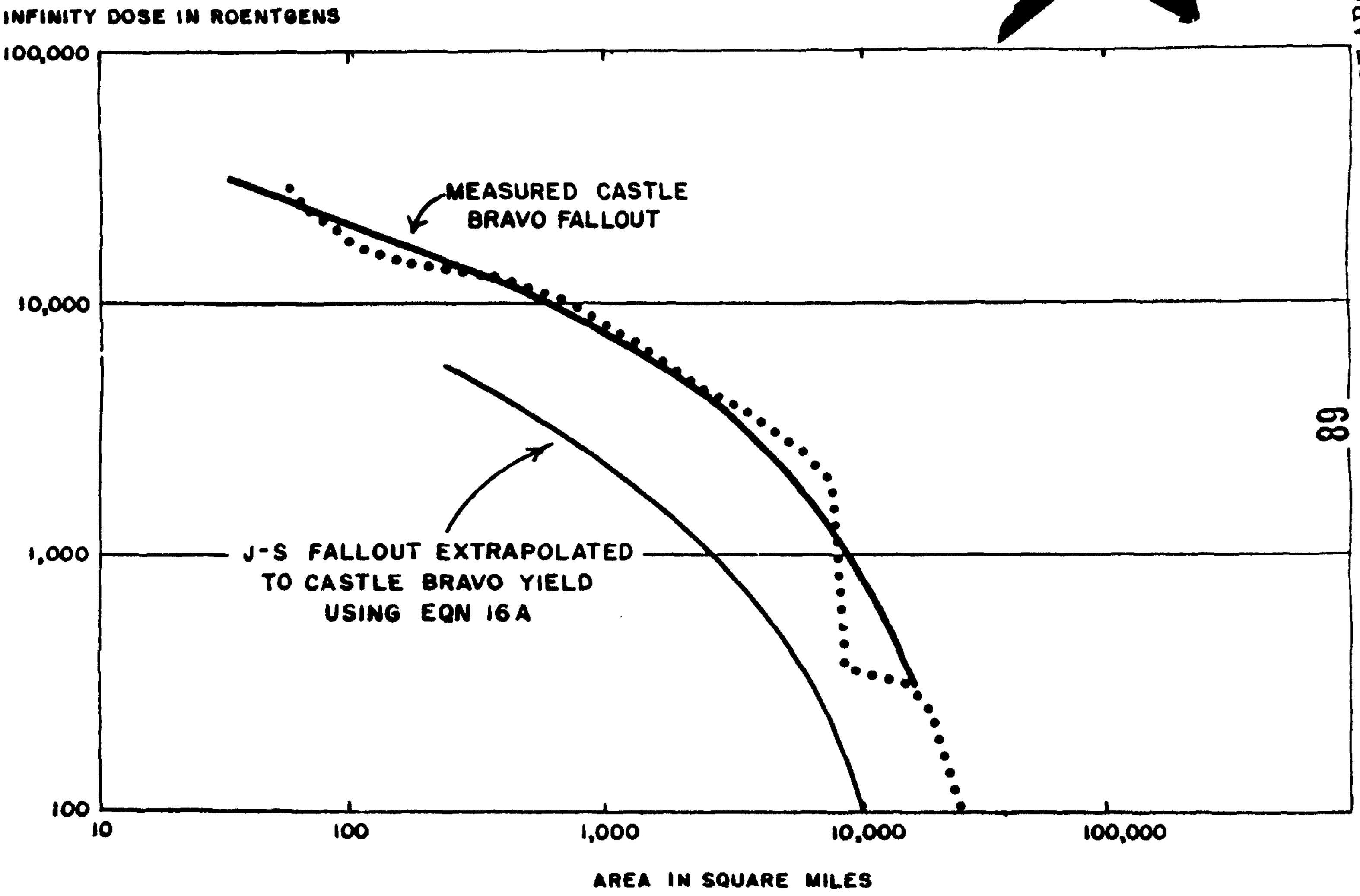


[redacted]

[redacted]

Figure #13

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~



[redacted]

REFERENCES: [redacted]

1. "Radioactive Fall-out from Atomic Bombs", Hq ARDC C3-36417, Nov 1953 (S-RD) and Supplement, by Lieutenant Colonel N. M. Lulejian.

2. UPSHOT-KNOTHOLE, Project 4.1, "The Radiation Hazards to Personnel within An Atomic Cloud", S-RD

3. Personal Communication with Col Houghton and Capt Steel of AFSWC

4. Operation U/K, WT-705, "Activities of the Special Weather Advisory Service", C-RD

5. Operation CASTLE, "Project 9.1, Cloud Photography", S-RD

6. "Radioactive Fall-out from Contact Burst Megaton Bombs", Hq ARDC C4-18098, S-RD by Lt Col Lulejian

7. Operation GREENHOUSE, Scientific Test Directors Report WT-26, Annex 6.5 Aug 1951, S-RD

8. Operation U/K, Project 4.7, "Beta-Gamma Skin Hazard in the Post Shot Contaminated Area," WT-746, C-RD

9. USNRDL-383, "Beta-Contact Hazards Associated with Gamma Radiation Measurements of Mixed Fission Products", by J. D. Teresi

10. Rand Report R-139, "The Radiation Hazard from an Atomic Bomb Cloud", 1949 (S-RD) by Cohen and Plesset

11. USNRDL-379, "Radiation Hazards to Aircrews Exposed to the Atomic Cloud of an Atomic Detonation" by Teresi

12. Preliminary Report on Operation CASTLE Project 2.5a, "Distribution and Intensity of Fall-out" ITR-915 (S-RD)

13. Preliminary Report, Operation CASTLE, Project 4.1, "Study of Response of Human Beings Accidentally Exposed to Significant Fall-out Radiation", ITR 923, S-RD

14. Operation JANGLE, Project 2.7, "Biological Injury from Particle Inhalation", by Falconer Smith, June 1952, WT-396, S-RD

15. AFSWP Report 507, Radioactive Fall-out Hazards from Surfact Bursts of Very High Yield Nuclear Weapons S-RD

16. Rand Report R-265-AEC "Transport and Early Deposition of Radioactive Debris from Atomic Explosions"

17. TUMBLER-SNAPPER Report on Radiological Safety, WT-558, Dec 52, S-RD

[redacted]

R[redacted]ATA
At[redacted]ct 1946

C4-23676
91

[redacted]

18. Operation UPSHOT-KNOTHOLE Report on Radiological Safety
19. "Radioactive Fall-out and Radex Plots" Air Weather Service Manual 105-3, Unclassified
20. "Meteorological Technical Report of Operation GREENHOUSE", by Cmdr Pate and Col George Taylor, Joint Task Force 3, Sept 1951, Secret
21. Schorr, M. G. and Gilfillan, E. S., "Predicted Scaling of Radiological Effects to Operational Weapons". JANGLE Project 2.0 (15 Jun 52) S-RD
22. R. K. Laurino, LJP Minvielle, E. T. Sheffield, R. F. Johnson, "Effects of Surface and Underground Nuclear Explosions", USNRDL PAD-10, WP 311.4, 30 Jun 52, Secret
23. "Consideration of Radioactive Contamination in the Major Overhaul of Aircraft Turbo-Jet Engines," USNRDL Report # 355, 1 May 1952, by H.A. Myers et al.

~~RESTRICTED DATA~~
~~Atomic Energy Act 1946~~

[redacted]

[redacted]

INITIAL DISTRIBUTION

AIR FORCE ACTIVITIES

COPY NO.	
1	Director of Operations, Headquarters USAF ATTN: Operations Analysis Div, Washington 25, D. C.
2	Director of Research & Development, Headquarters USAF ATTN: Armament Division, Washington 25, D. C.
3	The Surgeon General, Headquarters USAF, ATTN: Bio. Def. Br., Pre. Med. Div., Washington 25, D. C.
4	Director of Operations, Headquarters USAF ATTN: Asst. for Atomic Energy, Washington 25, D. C.
5	Asst. for Development Planning, Headquarters USAF Washington 25, D. C.
6	Deputy for Materiel Control, Asst. for Materiel Program Control, DCS/M, Headquarters USAF, ATTN: AFMPC-AE, Washington 25, D. C.
7	Director of Operations, Headquarters USAF Washington 25, D. C.
8	Director of Plans, Headquarters USAF ATTN: War Plans Div., Washington 25, D. C.
9	Director of Requirements, Headquarters USAF ATTN: AFDRQ-SA/M, Washington 25, D. C.
10	Director of Research and Development, Headquarters USAF ATTN: Combat Components Div., Washington 25, D.C.
11	Director of Intelligence, Headquarters USAF ATTN: AFCIN-1B2, Washington 25, D. C.
12-16	Col Leo V. Harmon, Special Asst for Nuclear Development Office of DCS/D, Headquarters USAF, Washington 25, D. C.
17	Asst Chief of Staff, Intelligence, Headquarters USAFE, APO 633, c/o PM, New York, N. Y.
18	Commander, 497th Reconnaissance Technical Squadron (Augmented) APO 633, c/o PM, New York, N. Y.

[redacted]

~~RES[illegible] DATA~~
~~At[illegible]ergy [illegible]t 1946~~

DOE ARCHIVES
C4-23676

[redacted]

19 Commander, Far East Air Forces, APO 925, c/o PM,
San Francisco, California

20 Commander, Alaskan Air Command, APO 942, c/o PM,
Seattle, Washington, ATTN: AAOTN

21 Commander, Northeast Air Command, APO 862, c/o PM,
New York, N. Y.

22 Commander, Strategic Air Command, Offutt AFB, Omaha, Nebr.
ATTN: Special Weapons Branch, Inspection Div., Inspector General

23 Commander, Strategic Air Command, Offutt AFB, Omaha, Nebr.
ATTN: Chief, Operations Analysis

24 Commander, Tactical Air Command, Langley AFB, Virginia
ATTN: Documents Security Branch

25 Commander, Tactical Air Command, ATTN: Maj Paul Andrae
Langley AFB, Virginia

26 Commander, Air Defense Command, Ent AFB, Colorado

27 Commander, Air Materiel Command, Wright-Patterson AFB, Ohio
ATTN: MCAIDS

28 Commander, Air Materiel Command, Wright-Patterson AFB, Ohio
ATTN: MCSW

29 Commander, Air Training Command, Scott AFB, Belleville, Ill.

30 Commander, Air Training Command, Scott AFB, Belleville, Ill.
ATTN: DCS/O GTP

31 Commander, Air Proving Ground Command, Eglin AFB, Florida
ATTN: AG/TRB

32 Commander, Flying Training Air Force, Waco, Texas
ATTN: Director of Observer Training

33 Commander, Crew Training Air Force, Randolph Field, Texas
ATTN: 2GTS, DCS/O

34 Commander, Headquarters, Technical Training Air Force,
Gulfport, Miss. ATTN: TA&D

35 Commander, Air University, Maxwell AFB, Alabama

[redacted]

~~RES[illegible] DATA~~
~~At[illegible]ergy [illegible]ct 1946~~

94

[redacted]

36 Commandant, Air Command & Staff School, Maxwell AFB, Ala.

37 Commandant, AF School of Aviation Medicine, Randolph AFB, Texas

38 Commander, Wright Air Development Center, Wright-Patterson AFB, Ohio ATTN: WCOESP

39 Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Massachusetts, ATTN: CRH

40 Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Massachusetts

41 Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex, ATTN: Chief, Technical Library Branch

42 Commandant, USAF Institute of Technology, Wright-Patterson AFB, Ohio, ATTN: Resident College

43 Commander, Lowry AFB, Denver, Colorado, ATTN: Dept. of Armament Training

44 Commander, 1009th Special Weapons Squadron, Headquarters USAF, Washington 25, D. C.

45 Commander, Lookout Mountain Laboratory, 8935 Wonderland Avenue, Hollywood, California

46 The RAND Corporation, 1700 Main Street, Santa Monica, California, ATTN: Nuclear Energy Division

47 Chief, Air Weather Service, Andrews AFB, Washington 25, D. C.

48 Commander, Western Development Division, P. O. Box 262 Inglewood, California, ATTN: Col Glasser, WDT

49 Col John F. Babcock, Air University, Maxwell AFB, Alabama

ARMY ACTIVITIES

50 Asst. Chief of Staff, G-1, D/A, Washington 25, D. C. ATTN: Human Relations and Research Board

51 Asst. Chief of Staff, G-2, D/A, Washington 25, D. C.

52 Asst. Chief of Staff, G-3, D/A, Washington 25, D. C. ATTN: Dep. C of S, G-3 (RR&SW)

53 Asst. Chief of Staff, G-4, D/A, Washington 25, D. C.

[redacted]

REST[redacted]TA

95

54 Chief of Ordnance, D/A, Washington 25, D. C.
ATTN: ORDTX-AR

55 Chief, Signal Officer, D/A, P&O Division,
Washington 25, D. C. ATTN: SIGOP

56 The Surgeon General, D/A, Washington 25, D. C.
ATTN: Chief, R&D Division

57 Chief Chemical Officer, D/A, Washington 25, D. C.

58 The Quartermaster General, CBR, Liaison Officer,
Research and Development Div., D/A, Washington 25, D.C.

59 Chief of Engineers, D/A, Washington 25, D. C.
ATTN: ENGNB

60 Chief of Transportation, Military Planning and
Intelligence Div., Washington 25, D. C.

61 Chief, Army Field Forces, Ft Monroe, Virginia

62 Commanding Officer, Chemical Corps Chemical and
Radiological Laboratory, Army Chemical Center,
Maryland, ATTN: Technical Library

NAVY ACTIVITIES

63 Commanding Officer, U.S. Naval Radiological Defense
Laboratory, San Francisco 24, California, ATTN:
Technical Information Division

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

64 Chairman, Research and Development Board, D/D,
Washington 25, D. C., ATTN: Technical Library

65 Commandant, National War College, Washington 25, D.C.
ATTN: Classified Records Section, Library

66 Commandant, Armed Forces Staff College, Norfolk 11,
Virginia, ATTN: Secretary

67 Commander, Field Command, Armed Forces Special Weapons
Project, P. O. Box 5100, Albuquerque, New Mexico

68 Chief, Armed Forces Special Weapons Project,
Washington 25, D. C.

RES[redacted]
At[redacted]t 1946

DOE ARCHIVES

69 Office of the Secretary of Defense, Weapons Systems Evaluation Group, Washington 25, D. C.

70 Office of the Secretary of Defense, Weapons Systems Evaluation Group, ATTN: Mr. Kenneth W. Erickson, Washington 25, D. C.

71 Operations Research Office, The Johns Hopkins University, 6410 Connecticut Avenue, ATTN: Kay Hafstad, Chevy Chase, Maryland

ATOMIC ENERGY COMMISSION ACTIVITIES

72 U.S. Atomic Energy Commission, Classified Documents Room, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (for DMA)

73 U.S. Atomic Energy Commission, 1901 Constitution Avenue, Washington 25, D. C., ATTN: Dr. Bugher, Div. of Biology & Medicine

74 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex., ATTN: Martin Lucero

75 Special Project Branch, Technical Information Service, Oak Ridge, Tennessee

76 Sandia Corporation, Sandia Base, Albuquerque, N. Mex. ATTN: Dr. Everett Cox

77 Chief, Inter-Agency Service Section, Technical Service Branch, Rm 1305, U.S. Atomic Energy Commission, ATTN: Mr. E. B. Parks, 1901 Constitution Avenue, Washington 25, D. C.

78 Manager of Operations, U.S. Atomic Energy Commission, P.O. Box 30, Ansonia Station, ATTN: Merril Eisenbud, New York 23, N. Y.

79 U. S. Atomic Energy Commission, Santa Fe Operations Office, P.O. Box 5400, Albuquerque, New Mexico

RE[redacted]DATA
At[redacted]1946